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(54) PARTICLE IMPLANTATION

(71) We, COMMISSARIAT A L'ENERGIE ATOMIQUE, of 29, rue de la Fédération, Paris 15e, France, a French company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of implantation of particles into a substrate and especially but not exclusively a method of ion implantation which permits of highly uniform implantation both at the surface and in depth. The invention is also concerned with a device for carrying out said method.

It is known that, in many industrial applications such as the manufacture of integrated circuits and especially in the case of MOS transistor circuits, it is necessary to direct a flux of particles onto a suitable crystalline substrate in order to dope said substrate. The doing agents can be introduced in the form of uncharged particles but are more commonly introduced in the form of ions, this technique being known as ion implantation into a substrate.

In order to ensure reliability and economic performance, methods of ion implantation must permit the achievement of highly homogeneous doping both at the surface and in depth. The many industrial designs adopted up to the present time have all been directed towards this objective.

In some methods of implantation, the target sample or substrate is stationary and a system of electrodes brought to periodic potentials is employed in order to deflect the beam of ionized particles in two perpendicular directions X and Y which are substantially parallel to the sample. The ion beam is usually of small size compared with the dimensions of the substrate and the deflection is obtained electrostatically by means of capacitor plates to which are applied, for example, symmetrical triangular voltages. This system suffers from physical limitations: edge effects, non-linearity of applied electrical signals, presence of uncharged particles, which can be minimized but not removed entirely. This system does not make it possible to guarentee homogeneity or, in other words, constancy of concentration of dopant at the surface and in volume cannot be ensured to a higher degree than about 2 to 5%.

In a second known method, a particle beam having a fixed direction is employed and the sample is displaced in two directions X, Y. This method is difficult to carry into effect since the mechanical movements in vacuum at constant speed over considerable distances (about ten centimetres, for example) are very difficult to obtain. Furthermore, the movements of displacement obtained by mechanical means take place at very low speed and cannot result in good homogeneity of the implantation if the intensity of the beam varies to a slight extent. Moreover, the low speed of displacement of the sample entails the need for low particle flux values and impairs the efficiency of the apparatus since the time of utilization is longer than in the first method in respect of an equal quantity of implanted material.

The present invention is directed to a method and a device for implanting a beam of particles into a substrate in such a manner as to overcome the disadvantages mentioned above and arising from inhomogeneity of implantation both at the surface and in volume.

In the method according to the invention, a beam of particles is directed on to a target in order to implant said particles into said target, said beam of particles being swept across the target in two mutually perpendicular directions, while said target is subjected to rotation about an axis which

is itself subject to rotation about a second axis substantially parallel to and spaced from the first axis, said axis being at least approximately parallel to the direction of the particle beam. Thus, each point of the target except the axial centre describes an epicycloid at the time of implantation, the axial centre describing a circle.

It has been established that these two means permit the achievement of substantial improvements in homogeneity of implantation since the variations in concentration of implanted particles do not exceed 1%. In accordance with a further feature of the invention, it is also possible to set the target (substrate) at a small angle of inclination of a few degrees (0 to 15°) with respect to the direction of the particle beam in order to ensure that said beam impinges upon the sample substrate at an oblique angle of incidence, thereby preventing or minimizing the effects of ion channelling within the crystal when this angle is suitably chosen. This inclination in conjunction with the double rotation of the substrate makes it possible to ensure better homogeneity of implantation in depth by obtaining a mean value of channelling effects.

The invention is also concerned with a device for the practical application of the method which will be described hereinafter.

Further characteristic features and advantages of the invention will in fact become more readily apparent from the following description of exemplified embodiments which are given solely by way of explanation and not in any limiting sense, reference being made to the accompanying drawings, in which:

Figure 1 diagramatically illustrates an ion implantation device according to the invention, provision being made for a target carrier-plate which can be inclined with respect to an axis of rotation;

Figure 2 illustrates a target carrier driving system for the implantation device according to the invention.

There is shown in Figure 1 one embodiment of the invention in which the particle beam represented schematically by the arrows such as those designated by the reference 2 impinges upon a target carrier-plate P′ which is inclined with respect to the general direction of the flux of ionized particles. The sweep system XY is represented by the electrodes 4, 6, 8 and 10 (deflecting electrodes) which permit sweeping along two axes X, Y by means of two supply-voltage sources (relative in one case to the direction X and in the other case to the direction Y) for delivering, the example, symmetrical triangular voltages having a judiciously chosen frequency ratio.

The complete assembly is placed within a vacuum chamber 14. The motor M drives a shaft A′ (by the system illustrated in Figure 2), said shaft carrying the carrier plate P′. The bellows seal 18 endows the apparatus with a certain degree of elasticity and facilitates disassembly of this latter. The ion beam is stopped-down by the diaphragm 20 and provision is also made for an electron trap 22 for removing the secondary electrons emitted during the bombardment. The mechanical arm 24 serves to extract samples from the magazine 26 in order to place and fix these latter on the carrier-plate P′, which is made of ferro-magnetic material, by means of a small sample-holding magnet. In this embodiment, the carrier-plate P′ can be inclined by means of a pivot 28 which serves to orient said carrier-plate P′ at an angle which is adjustable within the range 0 to 15 degrees with respect to the shaft A′.

In order to carry out the ion implantation operation, a sample is taken from the magazine 26 by means of the arm 24 and placed on the carrier-plate P′ which has been set at a predetermined angle of inclination. The motor M is then started-up so as to drive the shaft A′ and consequently the carrier-plate P′ in rotation, said shaft A′ being in turn rotationally coupled to a second shaft A which is not shown in this Figure but in Figure 2. Said second shaft A passes into the chamber 14 through a vacuum tight passage. The ion beam produced by a source (not shown) is then formed and swept by the device comprising the deflecting electrodes which are supplied by the two voltage sources.

The inclination of the sample with respect to the incident particle flux in conjunction with the rotation of the sample about its own axis serves to overcome inhomogeneities in depth of penetration of the particles within the crystalline target. The variations usually observed in the shape of the concentration profiles are due to variations in beam entrance angle with respect to the sample during irradiation (incident beam normal to the target at the center of this latter and divergent near its periphery).

A preliminary calibration which employs the method of back-scattering of charged particles in a substrate as a function of the angle of orientation makes it possible to determine the angle at which the number of back-scattered particles is of maximum value, that is, the angle at which particle channelling effects are limited to a minimum. In the case of a silicon substrate, the angle of 7°±1° is particularly favorable and results in very strong back-scattering of α-particles or protons, thus promoting

homogeneity of implantation in depth at a value of approximately 10% The fact of associating the rotation of the sample about its own axis with the angle aforementioned tends to produce a mean value of residual channelling effects and makes it possible to attain a homogeneity of the order of 1%.

There is shown in Figure 2 one embodiment of driving system for the device according to the invention.

Said device comprises a motor M coupled to a shaft A which rotates in the direction indicated by the arrow 30. Said shaft A couples the external motor M to the vacuum chamber 14 and is provided with an extension in the form of a carrier member P. A guide bush 32 is fitted in said carrier member and a shaft A′ which is the shaft of the toothed wheel 34 is rotatably mounted in said guide bush. Said toothed wheel 34 is disposed in meshing engagement with a circular toothed rack 36 which is coaxial with the shaft A. The shaft A′ which is secured to the sample carrier-plate P′ rotates within the carrier member P which is driven in rotation by the shaft A by means of the system comprising the toothed wheel 34 and rack 36. The target 38 is subjected to the ion implantation produced by the ion beam 40 which undergoes a double sweep by means of a deflecting system of similar design to that shown in Figure 1 but omitted from Figure 2. The device further comprises the diaphragm 20 and the electron trap 22.

Thus, each point of the substrate such as N describes an epicycloid except for the central point O which describes a circle. As in Figure 1, a mechanical arm (not shown in Figure 2) serves to place samples 38 on the carrier-plate P′. Said carrier-plate can be oriented in the particle flux by means of a pivot 42.

Another alternative embodiment which has been designed and developed consists in maintaining the carrier-plate P′ at right angles to its axis of rotation A′. In consequence, the complete mechanical system is oriented with respect to the incident beam 40 by means of the end-plate 60 which is set at an angle of a few degrees (7° in the case mentioned earlier) with respect to the initial direction shown in Figure 2. The device further comprises a unit 50 for measuring the current received by the target; this current can be measured by means of the current which flows through the shaft A since the passages such as those designated by the reference 52 are formed of insulating material. By way of example, the passage 52 is of Teflon (Trade Mark) and the speed of rotation of the shaft A is approximately ten revolutions per minute. By means of an electric supply not shown in the Figure, the electron trap 22 is brought to a negative potential of a few hundred volts. The vacuum created within the chamber 14 has a value of about 10^{-7} torr. A measurement carried out on an implanted sample having a diameter of about ten centimeters has served to establish that homogeneity of the bombardment was of the order of 1%, which gives clear evidence of a marked technical improvement.

WHAT WE CLAIM IS:—

1. A method of particle implantation in which a beam of particles is directed on to a target in order to implant said particles into said target, said beam of particles being swept across the target in two mutually perpendicular directions while said target is subjected to rotation about an axis which is itself subject to rotation about a second axis substantially parallel to and spaced from the first axis, said axes being at least approximately parallel to the direction of the particle beam.

2. A method according to claim 1, wherein said method is a method of ion implantation.

3. A method according to claim 1 or claim 2, wherein the target is set at a predetermined angle of inclination with respect to the direction of the particle beam.

4. A method according to claim 3, wherein said angle is within the range of 0° to 15°.

5. A device for particle implantation to carry out the method according to claim 1, wherein said device comprises:

a motor for driving a shaft which extends through a vacuum-tight passage and couples said motor to a carrier member located within a vacuum chamber,

means for deflecting a particle beam in two perpendicular directions lying in a plane at least approximately normal to the axis of the shaft,

a circular toothed rack carried by the vacuum chamber, a toothed wheel being disposed in meshing engagement with said toothed rack, and

a second shaft rotatable with the toothed wheel and which passes through the carrier member within a guide bush, said second shaft being adapted to support a carrier-plate for the target.

6. A device according to claim 5, wherein the target carrier-plate and its rotary shaft are mounted with fixed orientation with respect to the direction of the incident beam.

7. A device according to claim 5 or claim 6, including a mechanical arm for successively extracting sample targets from a magazine in order to place said targets on

said carrier-plate and for replacing said targets in the magazine after particle implantation.

8. A device according to claim 7, wherein said carrier-plate is made of ferro-magnetic material for attachment of the sample targets thereto by means of a holding magnet.

9. A method of particle implantation according to claim 1 and substantially as hereinbefore described.

10. A device for the application of the method of particle implantation according to claim 1, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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1490481 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

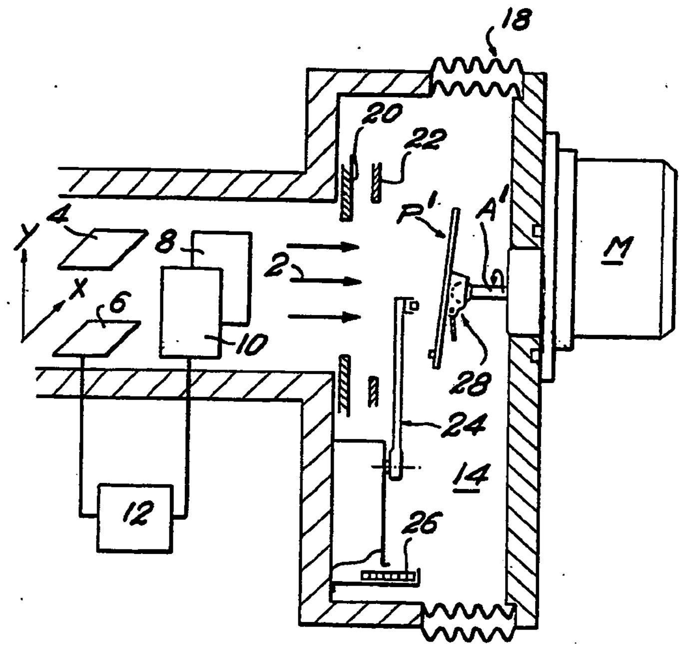

FIG. 1

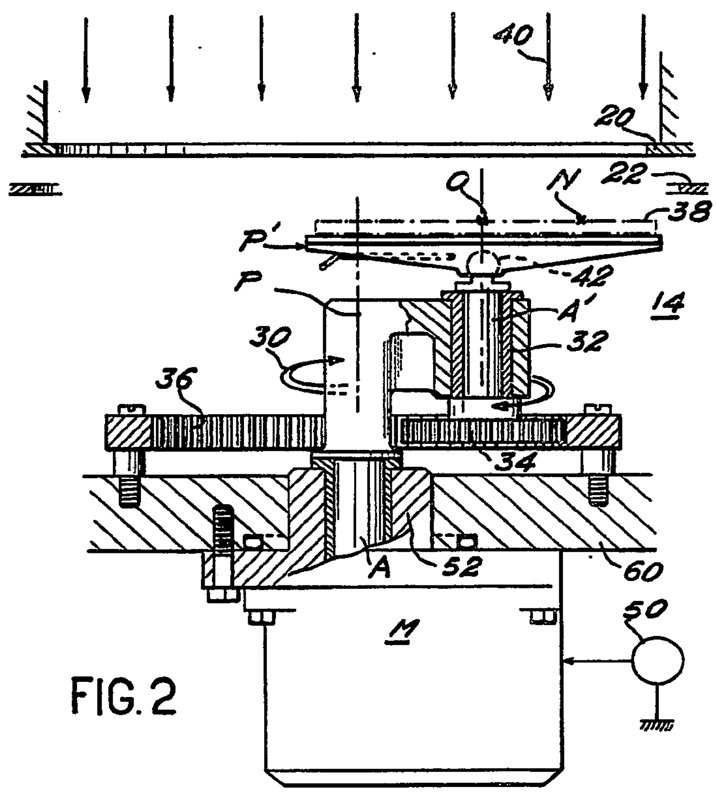

FIG. 2